Herringbone Microfluidic Mixer

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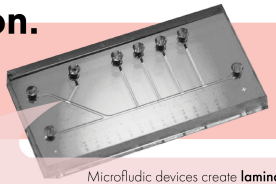
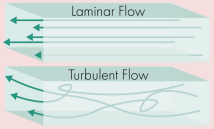
Introduction.

Microfluidic devices precisely manipulate microliters of liquids, which can help support the **growth of cells and tissues.**





Microfludic devices create **laminar flow** due to a low Reynolds number (low velocity of liquid and small channel size).

However, laminar flow hinders mixing of mediums of such as drugs or chemical reactions.

$$\text{Reynolds Number} = \frac{\rho V D}{\mu}$$

ρ = density of fluid
V = velocity of fluid
D = diameter of pipe
μ = dynamic viscocity

In this work, we make a microfluidic mixer that disrupts laminar flow.

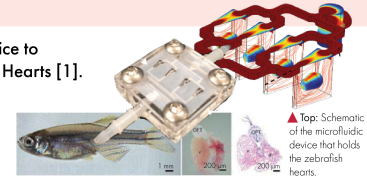
Impact of LLSE's Work.

The Laboratory for Living Systems Engineering (LLSE) at USC develops microfluidic devices to culture cellular growth and quantify tissue function. The figures below showcase their work.

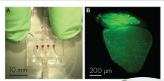
Microfluidic Device to Image Zebrafish Hearts [1].

Researchers at LLSE have recently developed a device to observe the regeneration process of zebrafish hearts.

With their work, we may one day understand the mechanics of regeneration to help develop medications for heart disease.

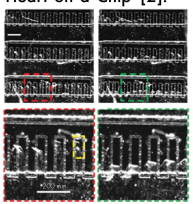


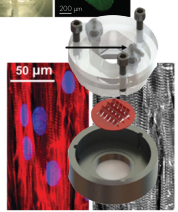
▲ **Top:** Schematic of the microfluidic device that holds the zebrafish hearts.



▲ **Middle:** Images of the zebrafish and size of their hearts.
◀ **Bottom:** Zebrafish hearts while in device and imaged under fluorescence.

Heart-on-a-Chip [2].



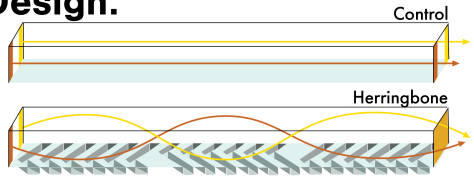


▲ **Top:** The microfluidic device with cantelevers and heart cells for device.
◀ **Left:** Images of the heart cells contracting the cantelevers.

Dr. McCain also worked on a project to engineer heart cells into thin films to understand contraction during diastole and systole.

In the future, researchers can screen drugs to understand the effects on the heart and other organ systems.

Design.

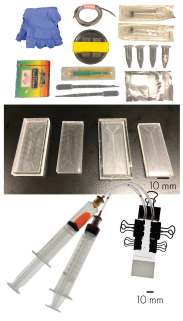


Created by Stroock et al. 2002 at Harvard University, the Herringbone mixer features grooves that facilitate mixing and turbulent flow [3].

Methods.

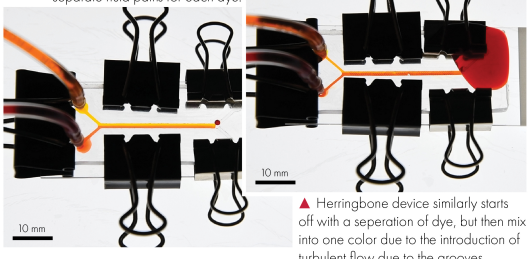
Constructing the device

1. Micromill polycarbonate mold for both control and herringbone device & smooth via sanding [4].
2. Pour silicone or polydimethylsiloxane (PDMS) into the mold & heat cure.
3. Puncture 2 holes using biopsy punch for syringe tubing connection to enter.
4. Puncture 1 hole for fluid to exit the device.
5. Clip the PDMS device to a glass slide using binder clips.
6. Attach tubing and syringes via barbed connector.
7. Push dyes through the device and observe flows.



▶ Top: Components of the herringbone device
Middle: Polycarbonate molds and PDMS devices
Bottom: The complete device constructed with 2 syringes, food coloring dye, and microfluidic device.

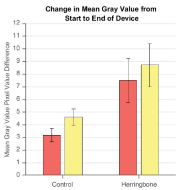
▼ Control device has no grooves and has distinct seperation of color and maintained separate fluid paths for each dye.

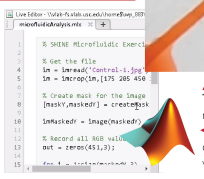


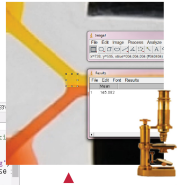
▲ Herringbone device similarly starts off with a seperation of dye, but then mix into one color due to the introduction of turbulent flow due to the grooves.

Results.

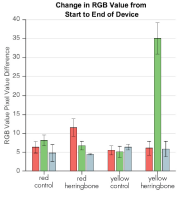
Using MATLAB and ImageJ, mean gray values and red, green, blue (RGB) values were pulled from the start and end of the channels.







▲ **Top:** ImageJ analysis of mean gray value
◀ **Left:** MATLAB analysis of the RGB values



Over 5 frames of a perfusion video per device, the herringbone mixer had a greater change in mean gray value and RGB values control, showing that the dyes mixed more throughly compared to the control device.
▲ **Top Left:** The red channel in the herringbone device had a change of mean gray pixel value of 7.500± 3.477 while the yellow channel had a change of 8.721±3.417.
◀ **Bottom Left:** When evaluating RGB values, the red channel had the greatest change in its red pixel value by 11.575±4.560 while the yellow value had the greatest change in its green pixel value by 35.037±8.281.

Average Change in RGB Value from Start to End of Device

	Red Control			Yellow Control			Red Herringbone			Yellow Herringbone		
	Red	Green	Blue	Red	Green	Blue	Red	Green	Blue	Red	Green	Blue
Average	6.373	8.174	4.841	5.576	5.199	6.395	11.575	6.812	4.531	6.125	35.037	5.944
Standard Deviation	3.043	2.912	4.376	2.386	2.981	1.472	4.560	2.256	0.316	3.602	8.281	4.085

Average Change in Mean Gray Value from Start to End of Device

	Red Control	Yellow Control	Red Herringbone	Yellow Herringbone
Average	3.182	4.606	7.500	8.721
Standard Deviation	1.065	1.283	3.477	3.417

Next Steps.

- Work on my own microfluidic device that separates bacteria from blood
- Major in biomedical engineering in college and join a research lab during my time there

Reflection.

Tips for future students: take advantage of all the resources at SHINE, especially mentors and teammates because some of the people you may meet here may change your life. Be willing to take risk and be sincere and genuine with what you do.

References.

[1] Yip, J. K., Harrison, M., Villafuerte, J., Fernandez, G. E., Petersen, A. P., Lien, C.-L., & McCain, M. L. (2020). Extended culture and imaging of normal and regenerating adult zebrafish hearts in a fluidic device. Lab on a Chip, 20(2), 274–284. **[2]** Agarwal, A., Goss, J. A., Cho, A., McCain, M. L., & Parker, K. K. (2013). Microfluidic heart on a chip for higher throughput pharmacological studies. Lab on a Chip, 13(18), 3599–3608. **[3]** Stroock, A. D., Dertinger, S. K. W., Ajdari, A., Mezić, I., Stone, H. A., & Whitesides, G. M. (2002). Chaotic Mixer for Microchannels. Science, 295(5555), 647–651. **[4]** Yen, D. P., Ando, Y., & Shen, K. (2016). A cost-effective micromilling platform for rapid prototyping of microdevices. Technology, 4(4), 234–239.

Acknowledgements.

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